Vol. 2, No. 1, April 2023, pp. 17-31
p-ISSN: 2963-8577
e-ISSN: 2964-3511
DOI: 10.57102/jescee.v2i1.31

JESCEE
Journal of Emerging Supply Chain, Clean Energy, and Process Engineering

STUDY OF DISTRIBUTION TRANSFORMER VOLTAGE DROPS IN FEEDER 5 OUT GOING DISTRICTS 4 AND 6 AT PT. PLN (PERSERO) TARAKAN CITY, NORTH KALIMANTAN

Marthen Arifin[1*], Ismit Mado[1], Achmad Budiman[1], Choirul Anwar[2], Samuel Nathanael[2]
[1]Department of Electrical Engineering, Universitas Borneo Tarakan, North Kalimantan, Indonesia
[2]ULP PT. PLN (Persero) Tarakan, Tarakan City, North Kalimantan, Indonesia

Abstract
This research aims to determine the low-voltage drop that occurs at the substation and customer side. The voltage drop is affected by many factors including line resistance, line current, power factor, and line length. The need for electric power is increasing every year, causing power losses and voltage drops in the network to be a major concern. This research was conducted at Feeder 5 out going villages 4 and 6, one of the areas of PT. PLN in Tarakan City. The research data is voltage measurement data. This research applies analytical calculations with a quantitative descriptive method compared to calculations based on ETAP software. The allowable voltage drop by SPLN is 5% of the nominal voltage. The results of the analysis show that the voltage drop that occurs on average is still within the limits permitted by the SPLN, namely below 5% of the nominal voltage.

Keywords:
Voltage drop; low voltage; distribution transformer; simulation

Article History:
Received: February 3rd, 2023
Revised: March 8th, 2023
Accepted: April 26th, 2023
Published: April 30th, 2023

Corresponding Author:
Marthen Arifin
Department of Electrical Engineering, Universitas Borneo Tarakan, Indonesia
Email: marthenarifin2103@gmail.com

1. Introduction

Electricity is an energy that is needed by society. This can be seen from the development of society, the need for electrical energy also increases. Therefore, the quality of electrical energy is very important in efforts to improve service to the community. However, the limited distribution of electrical energy where the generator is located far enough from the load center can cause a voltage drop. This problem can cause damage to household electrical equipment. Causes of voltage drop include line resistance, line current, power factor, and line length [1]. Previous researchers have studied this voltage drop a lot. one of them is influenced by the length of the conductor and the impedance value, where the value is affected by the value of the resistance and reactance of the line [2]. Analysis of the voltage drop in low voltage distribution networks has been carried out by researchers, such as Hamles L. Latupeirissa et al. This research analyzes the voltage loss in the 380/220 Volt low voltage network (JTR) at the Politeknik Negeri Ambon distribution substation. Where in this study aims: (i) to calculate how much voltage drop occurs in the secondary network; (ii) calculating the voltage drop correction on the secondary network. The types of data needed to carry out the calculation analysis: (i) standard data on cable types and sizes; (ii) the type and number of buses, as well as the length of the distribution channel; (iii) data of substations and distribution transformers; (iv) loading data. While the analysis of the calculation of the voltage drop in this study is focused on (i) determining the percentage of voltage drop; (ii) determining the ideal cable cross-sectional area and (iii) calculating the value of the voltage for each bus, the current in the inter-bus channel [1] and Kurniawati Naim et al., reconfigured the JTR between BTN Hamzy and BTN Antara to determine power losses and voltage drop [3]. Some researchers focus on examining the losses caused by voltage drops in the distribution network. Hontong et al., analyzed power losses caused by load imbalances that always occur in an electric power distribution network system [4]. Deni Mulyadi analyzes the effect of current on the neutral phase of the transformer [5]. Baqaruzi and Ali Muhtar analyzed the voltage drop and losses due to the influence of the use of distributed generation in the 20 kV primary distribution system, namely a small power generation system in the intermediate voltage distribution network [6].

This research will analyze the voltage drop in the low-voltage distribution network of PT. PLN (Persero) Tarakan City, outgoing Villages 4 and 6 which are one of the outputs from Feeder 5. This research is in collaboration with PT. PLN (Persero) Tarakan and Department of Electrical Engineering, Universitas Borneo Tarakan for 3 months, both through field studies and simulations conducted at the Power System Stability Laboratory.

2. Theory Foundation

A. Distribution System

The electric power distribution system covers all 20 kV intermediate voltage networks and all 380/220 V low-voltage networks up to the customer. The medium voltage network (JTM) is often referred to as the primary distribution network, while the low voltage network (JTR) is often referred to as the secondary distribution network.

The electric power distribution network can be classified into 2 parts of the system, namely:

Primary Distribution Network

Primary distribution is a distribution network of medium voltage electricity (20 kV). The primary distribution network is the feeder network. The primary distribution network starts from the secondary side of the power transformer that is installed at the substation to the primary side of the distribution transformer that is installed at the poles of the line.

Secondary Distribution Network

Secondary distribution is an electric power network that belongs to the low voltage category (380/220 Volt system). The secondary distribution network starts from the secondary side of the distribution transformer and ends at the customer's meter as shown in Fig. 1 below [7].

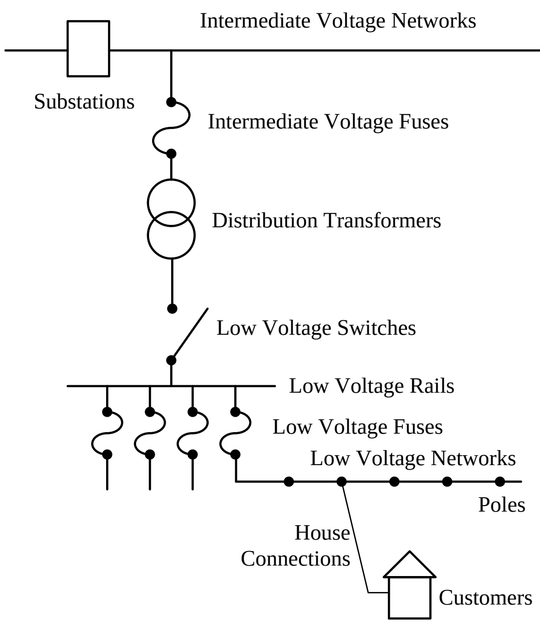

Figure 1. Secondary Distribution Network

B. Drop Voltage

Voltage drop is the amount of voltage lost in a conductor. The voltage drop on electric power lines is generally directly proportional to the length of the line and the load and inversely proportional to the cross-sectional area of the conductor. The magnitude of the voltage drop is expressed in percent or volts. The amount of the lower and upper limits is determined by the provisions regulated in the SPLN. Calculation of the voltage drop at certain limits by only calculating the magnitude of the resistance can still be considered. But in network systems, especially in intermediate voltage systems, inductance and capacitance issues are taken into account because their values are quite significant.

Voltage drop can be defined as [8]:

$$\Delta \boldsymbol{V} = \boldsymbol{V_s} - \boldsymbol{V_r} \quad (1)$$

where:

$\Delta \boldsymbol{V}$ = drop voltage (Volt)
$\boldsymbol{V_s}$ = the voltage on the sending side of the low-voltage distribution transformer (Volt)
$\boldsymbol{V_r}$ = load receiving voltage/consumer (Volt)

Due to the resistance in the conductor, the voltage received by the consumer ($\boldsymbol{V_r}$) will be less than the sending voltage ($\boldsymbol{V_s}$), so that the voltage drop ($\boldsymbol{V_{drop}}$) is the difference between the voltage at the sending end and the voltage at the receiving end.

The relative voltage drop is called voltage regulation ($\boldsymbol{V_R}$) and is expressed by the formula [8]:

$$\boldsymbol{V_R} = \frac{\boldsymbol{V_s} - \boldsymbol{V_r}}{\boldsymbol{V_r}} \times \mathbf{100}\% \quad (2)$$

In the calculation, it is assumed that the loads are a balanced three-phase load and the power factor ($\cos \boldsymbol{\varphi}$) is between 0.6 to 0.85 points.

The voltage drop for a three-phase network system can be calculated based on the relationship approach formula as follows [6]:

$$\boldsymbol{V_{drop}} = \sqrt{\mathbf{3}} \times \boldsymbol{I} \times \boldsymbol{L}\ (\boldsymbol{R} \cos \boldsymbol{\varphi} + \boldsymbol{X} \sin \boldsymbol{\varphi}) \quad (3)$$

where:

$\boldsymbol{V_{drop}}$ = drop voltage (Volt)
$\boldsymbol{I}$ = load current (Ampere)
$\boldsymbol{L}$ = conductor length (meters)
$\boldsymbol{R}$ = resistance (Ohm/km)
$\boldsymbol{X}$ = reactance (Ohm/km)
$\boldsymbol{\varphi}$ = power factor angle

3. Methods

A. Research Framework

This research was conducted with the following stages:

1. Literature Study
   In this step, we will collect journals and articles related to the voltage drop in the distribution transformer on the low voltage side.
2. Collect data
   In this step, will collect data on PT. PLN (Persero) Tarakan City. The data taken is in the form of measurement data in the field, data single line diagram feeder 5 out going Villages 4 and 6.
3. Voltage Drop Analysis
   In this step, we will analyze the voltage drop on the distribution transformer on the low voltage side of feeder 5 out going Villages 4 and 6 using voltage measurement data from field measurements. The results of calculation data based on measurements and simulation data based on ETAP software will be compared using the mean absolute percentage error (MAPE) calculation [9].
4. Final
   The results of the voltage drop analysis on the low voltage side distribution transformer on feeder 5 out going Villages 4 and 6 are the recommendations given for voltage drop analysis to PT. PLN (Persero) Tarakan City.

B. Data

The data needed in this study are primary and secondary data.

1. Primary data, form:
   – voltage
   – load current
   – power factor
   – the length and cross-sectional area of the conducting channel
2. Secondary data, form:
   – single line out going Villages 4 and 6.

C. Technique of Data Collection

Following are the stages in collecting primary and secondary data, namely:

1. Primary data
   – voltage measurements were carried out on the PHB TR and MCB at the consumer's house at the research location, using a digital ampere meter.
   – measurement of the load current on the MCB using a digital ampere meter.
2. Secondary data
   – single line out going chart of villages 4 and 6 obtained from PT. PLN (Persero) Tarakan City.

D. Data Analysis

As for how to analyze the data with the following stages:

1. The collected data will be analyzed with the help of Ms Excel.
2. Make a voltage drop simulation.
3. Comparing the analysis results with the simulation results using the MAPE equation.

4. Results and Discussion

A. Calculation of the Voltage Drop of Measurement Results Data

This research was conducted at PT. PLN (Persero) Tarakan City on Feeder 5 out going Villages 4 and 6. This voltage drop calculation is based on direct measurement data in the field, where researchers measure the voltage at PHB as the sending voltage and the voltage at the consumer as the voltage receiver. The calculation results consist of the calculation of the voltage drop and voltage regulation on each phase

1. Voltage Drop Calculation

The calculation of the voltage drop is calculated using equation (1). The calculation results are presented in Table 1 below.

Table 1. Voltage drop calculation

Substations	Sending voltage (V_s)			Receive voltage (V_r)			Drop voltage (ΔV)		
	R	S	T	R	S	T	R	S	T
KPE 155	222	223	221	220	222	219	2	1	2
KPE 92	223	222	224	222	220	223	1	2	1
KPE 42	215	216	214	213	214	212	2	2	2
KPE 62	211	210	210	209	208	208	2	2	2
KPE 228	224	223	225	222	221	223	2	2	2
KPE 399	222	226	224	220	224	222	2	2	2
KPE 36	221	221	223	219	219	221	2	2	2
KPE 52	223	223	222	221	221	220	2	2	2
KPE 388	227	226	226	225	224	223	2	2	3
KPE 165	223	225	224	221	223	222	2	2	2
KPE 53	222	223	223	220	221	221	2	2	2

KPE 352	223	225	224	221	223	222	2	2	2
MBR 37	222	223	221	220	221	219	2	2	2
KPE 166	229	224	223	221	222	220	8	2	3
MBR 324	224	225	226	222	223	224	2	2	2
MBR 72	219	219	220	217	217	219	2	2	1
MBR 133	222	220	221	221	219	219	1	1	2
MBR 112	223	223	224	222	220	221	1	3	3
KRN 267	224	226	225	221	224	223	3	2	2
MBR 423	226	225	226	224	223	224	2	2	2
MBR 229	220	223	221	219	222	220	1	1	1
MBR 314	223	222	223	220	221	221	3	1	2
KRN 78	222	223	223	220	221	220	2	2	3
KRN 130	223	224	223	220	221	220	3	3	3
KRN 150	220	222	220	219	220	219	1	2	1
KRN 387	223	224	224	221	222	221	2	2	3
KRN 209	223	221	223	221	220	221	2	1	2
TJP 129	225	224	223	223	221	222	2	3	1
TJP 361	220	221	221	219	220	220	1	1	1
JTP 126	222	222	222	219	220	219	3	2	3
TJP 167	223	224	222	220	221	220	3	3	2

From table 1, it can be seen how much the sending voltage is from PHB and the voltage received by consumers, and how much voltage drop or voltage difference occurs in Feeder 5 Out Going Villages 4 and 6.

2. Voltage Regulation Calculation

Calculation of voltage regulation based on equation (2). After the voltage drop value is analyzed then the voltage regulation is calculated. The calculation results are presented in Table 2 below.

Table 2. Voltage Regulation Calculation

Substations	Sending (V_s)			Receive voltage (V_r)			Regulation voltage (%)		
	R	S	T	R	S	T	R	S	T
KPE 155	222	223	221	220	222	219	0,009091	0,004505	0,009132
KPE 92	223	222	224	222	220	223	0,004505	0,009091	0,004484
KPE 42	215	216	214	213	214	212	0,00939	0,009346	0,009434
KPE 62	211	210	210	209	208	208	0,009569	0,009615	0,009615
KPE 228	224	223	225	222	221	223	0,009009	0,00905	0,008969
KPE 399	222	226	224	220	224	222	0,009091	0,008929	0,009009
KPE 36	221	221	223	219	219	221	0,009132	0,009132	0,00905
KPE 52	223	223	222	221	221	220	0,00905	0,00905	0,009091
KPE 388	227	226	226	225	224	223	0,008889	0,008929	0,013453
KPE 165	223	225	224	221	223	222	0,00905	0,008969	0,009009
KPE 53	222	223	223	220	221	221	0,009091	0,00905	0,00905
KPE 352	223	225	224	221	223	222	0,00905	0,008969	0,009009
MBR 37	222	223	221	220	221	219	0,009091	0,00905	0,009132

KPE 166	229	224	223	221	222	220	0,036199	0,009009	0,013636
MBR 324	224	225	226	222	223	224	0,009009	0,008969	0,008929
MBR 72	219	219	220	217	217	219	0,009217	0,009217	0,004566
MBR 133	222	220	221	221	219	219	0,004525	0,004566	0,009132
MBR 112	223	223	224	222	220	221	0,004505	0,013636	0,013575
KRN 267	224	226	225	221	224	223	0,013575	0,008929	0,008969
MBR 423	226	225	226	224	223	224	0,008929	0,008969	0,008929
MBR 229	220	223	221	219	222	220	0,004566	0,004505	0,004545
MBR 314	223	222	223	220	221	221	0,013636	0,004525	0,00905
KRN 78	222	223	223	220	221	220	0,009091	0,00905	0,013636
KRN 130	223	224	223	220	221	220	0,013636	0,013575	0,013636
KRN 150	220	222	220	219	220	219	0,004566	0,009091	0,004566
KRN 387	223	224	224	221	222	221	0,00905	0,009009	0,013575
KRN 209	223	221	223	221	220	221	0,00905	0,004545	0,00905
TJP 129	225	224	223	223	221	222	0,008969	0,013575	0,004505
TJP 361	220	221	221	219	220	220	0,004566	0,004545	0,004545
TJP 126	222	222	222	219	220	219	0,013699	0,009091	0,013699
TJP 167	223	224	222	220	221	220	0,013636	0,013575	0,009091

3. Calculation of 1 Phase Load Voltage Drop

Calculation of the 1-phase load voltage drop using equation (3). In this equation to test the magnitude of the voltage drop that occurs on low voltage lines using current data, circuit resistance, circuit reactance, cable length.

Table 3. Calculation of 1 phase load voltage drop

Substations	Current			Cos	Sin	Resistance			Reactance			Length	Cable length SR			Voltage drop		
	R	S	T	φ	φ	R	S	T	R	S	T	Cable JTR	R	S	T	R	S	T
KPE 155	6,11	4,04	4,03	0,85	0,526	0,311	0,302	0,300	0,075	0,074	0,074	500	20	13	12	1,857	1,192	1,184
KPE 92	5,09	4,91	6,11	0,85	0,526	0,247	0,247	0,246	0,060	0,060	0,060	400	15	15	14	1,231	1,188	1,471
KPE 42	6,18	4,02	4,04	0,85	0,526	0,304	0,300	0,302	0,074	0,074	0,074	500	15	12	13	1,840	1,181	1,192
KPE 62	6,04	4,11	3,26	0,85	0,526	0,364	0,358	0,361	0,089	0,088	0,088	600	17	13	15	2,150	1,442	1,152
KPE 228	4,24	3,09	4,05	0,85	0,526	0,387	0,385	0,385	0,095	0,095	0,095	650	13	12	12	1,606	1,167	1,529
KPE 399	5,21	3,47	4,17	0,85	0,526	0,323	0,326	0,324	0,079	0,080	0,079	540	12	14	13	1,647	1,106	1,324
KPE 36	5,78	5,01	4,58	0,85	0,526	0,302	0,302	0,304	0,074	0,074	0,074	500	13	13	15	1,706	1,479	1,363
KPE 52	5,25	4,06	4,01	0,85	0,526	0,331	0,333	0,331	0,081	0,081	0,081	550	14	15	14	1,703	1,322	1,300
KPE 388	4,54	4,21	3,71	0,85	0,526	0,300	0,300	0,302	0,074	0,074	0,074	500	12	12	13	1,334	1,237	1,095
KPE 165	6,07	4,48	4,18	0,85	0,526	0,338	0,336	0,337	0,083	0,082	0,083	560	15	13	14	2,010	1,472	1,379
KPE 53	5,76	4,93	4,65	0,85	0,526	0,327	0,324	0,323	0,080	0,079	0,079	540	15	13	12	1,843	1,565	1,470
KPE 352	4,12	4,78	3,22	0,85	0,526	0,317	0,321	0,320	0,078	0,078	0,078	530	12	15	14	1,280	1,503	1,008
MBR 37	4,28	3,11	3,74	0,85	0,526	0,414	0,418	0,414	0,102	0,103	0,102	700	12	15	12	1,735	1,273	1,516
KPE 166	4,93	3,15	3,06	0,85	0,526	0,347	0,349	0,345	0,085	0,085	0,085	576	15	16	13	1,676	1,075	1,033
MBR 324	3,57	3,52	4,55	0,85	0,526	0,324	0,321	0,324	0,079	0,079	0,079	534	15	13	15	1,130	1,106	1,441
MBR 72	4,12	4,49	3,41	0,85	0,526	0,314	0,312	0,312	0,077	0,076	0,076	520	14	12	12	1,267	1,370	1,040

MBR 133	5,22	5,02	4,88	0,85	0,526	0,303	0,310	0,307	0,074	0,075	0,075	505	12	17	15	1,549	1,521	1,466
MBR 112	5,51	6,01	5,98	0,85	0,526	0,335	0,340	0,339	0,082	0,083	0,083	556	14	18	17	1,805	1,999	1,982
KRN 267	4,01	5,72	5,63	0,85	0,526	0,347	0,351	0,351	0,085	0,086	0,086	583	12	15	15	1,364	1,967	1,936
MBR 423	4,07	3,77	4,32	0,85	0,526	0,365	0,367	0,360	0,089	0,090	0,089	606	15	17	12	1,452	1,355	1,525
MBR 229	4,89	4,93	3,87	0,85	0,526	0,305	0,309	0,307	0,074	0,075	0,075	503	14	17	16	1,458	1,488	1,163
MBR 314	3,14	3,56	3,91	0,85	0,526	0,377	0,379	0,383	0,093	0,093	0,094	636	12	13	16	1,161	1,321	1,465
KRN 78	5,04	4,11	3,89	0,85	0,526	0,350	0,346	0,346	0,086	0,085	0,085	578	16	13	13	1,726	1,392	1,317
KRN 130	4,97	3,83	4,01	0,85	0,526	0,403	0,403	0,402	0,099	0,099	0,099	679	13	13	12	1,963	1,513	1,579
KRN 150	4,18	3,24	3,24	0,85	0,526	0,348	0,346	0,350	0,085	0,085	0,086	580	14	12	15	1,425	1,097	1,109
KRN 387	3,68	4,89	2,62	0,85	0,526	0,392	0,392	0,393	0,096	0,096	0,096	654	15	15	16	1,411	1,876	1,008
KRN 209	4,52	4,56	4,94	0,85	0,526	0,351	0,353	0,353	0,086	0,087	0,087	590	12	13	13	1,555	1,575	1,706
TJP 129	4,02	4,23	3,88	0,85	0,526	0,311	0,313	0,309	0,076	0,076	0,076	515	14	15	12	1,225	1,295	1,173
TJP 361	4,37	6,11	5,29	0,85	0,526	0,307	0,312	0,308	0,075	0,076	0,075	512	12	16	13	1,314	1,867	1,597
TJP 126	4,12	4,63	2,45	0,85	0,526	0,453	0,455	0,454	0,112	0,112	0,112	766	13	15	14	1,827	2,065	1,090
TJP 167	3,67	4,07	3,82	0,85	0,526	0,335	0,332	0,336	0,082	0,082	0,082	556	14	12	15	1,202	1,323	1,256

Table 3 is the result of the calculation of the 1-phase load voltage drop, based on the distance from the PHB to the consumer.

B. Calculation of Voltage Drop from Simulation

This research uses ETAP software, to compare the value of the voltage drop that occurs in measurements and simulations. The data used in the ETAP software is in the form of measurement results and field data observations.

1. Convert The 3 Phase Voltage Value to 1 Phase

Before the researcher analyzes the voltage drop further by using the existing equation, the researcher previously converted the 3-phase voltage to 1-phase voltage with the following equation:

$$V_{3\Phi} = \sqrt{3} \times V_{1\Phi}$$

Where the conversion results will be displayed in Table 4 below.

Table 4. Convert the 3 phase voltage value to 1 phase

Substations	Voltage	Sending voltage 3Φ			$\sqrt{3}$	Voltage			Receice voltage 1Φ		
	Sending 3Φ	R	S	T		R	S	T	R	S	T
KPE 155	380	379	379	379	1,73	220	220	220	219	219	219
KPE 92	380	379	379	379	1,73	220	220	220	219	219	219
KPE 42	380	379	379	379	1,73	220	220	220	219	219	219
KPE 62	380	379	379	379	1,73	220	220	220	219	219	219
KPE 228	380	379	379	379	1,73	220	220	220	219	219	219
KPE 399	380	379	379	379	1,73	220	220	220	219	219	219
KPE 36	380	379	379	379	1,73	220	220	220	219	219	219
KPE 52	380	379	379	379	1,73	220	220	220	219	219	219
KPE 388	380	379	379	379	1,73	220	220	220	219	219	219
KPE 165	380	379	379	379	1,73	220	220	220	219	219	219
KPE 53	380	379	379	379	1,73	220	220	220	219	219	219
KPE 352	380	379	379	379	1,73	220	220	220	219	219	219

MBR 37	380	379	379	379	1,73	220	220	220	219	219	219
KPE 166	380	379	379	379	1,73	220	220	220	219	219	219
MBR 324	380	379	379	379	1,73	220	220	220	219	219	219
MBR 72	380	379	379	379	1,73	220	220	220	219	219	219
MBR 133	380	379	379	379	1,73	220	220	220	219	219	219
MBR 112	380	379	379	379	1,73	220	220	220	219	219	219
KRN 267	380	379	379	379	1,73	220	220	220	219	219	219
MBR 423	380	379	379	379	1,73	220	220	220	219	219	219
MBR 229	380	379	379	379	1,73	220	220	220	219	219	219
MBR 314	380	379	379	379	1,73	220	220	220	219	219	219
KRN 78	380	379	379	379	1,73	220	220	220	219	219	219
KRN 130	380	379	379	379	1,73	220	220	220	219	219	219
KRN 150	380	379	379	379	1,73	220	220	220	219	219	219
KRN 387	380	379	379	379	1,73	220	220	220	219	219	219
KRN 209	380	379	379	379	1,73	220	220	220	219	219	219
TJP 129	380	379	379	379	1,73	220	220	220	219	219	219
TJP 361	380	379	379	379	1,73	220	220	220	219	219	219
TJP 126	380	379	379	379	1,73	220	220	220	219	219	219
TJP 167	380	379	379	379	1,73	220	220	220	219	219	219

2. Drop Voltage Calculation

The calculation of the voltage drop is calculated using equation (1). After the 3-phase voltage is converted to 1-phase voltage, it will then be analyzed. The results of this equation will then be displayed in Table 5 below.

Table 5. Drop voltage calculation

Substation	Sending voltage			Receive voltage			Drop voltage		
	R	S	T	R	S	T	R	S	T
KPE 155	220	220	220	219	219	219	1	1	1
KPE 92	220	220	220	219	219	219	1	1	1
KPE 42	220	220	220	219	219	219	1	1	1
KPE 62	220	220	220	219	219	219	1	1	1
KPE 228	220	220	220	219	219	219	1	1	1
KPE 399	220	220	220	219	219	219	1	1	1
KPE 36	220	220	220	219	219	219	1	1	1
KPE 52	220	220	220	219	219	219	1	1	1
KPE 388	220	220	220	219	219	219	1	1	1
KPE 165	220	220	220	219	219	219	1	1	1
KPE 53	220	220	220	219	219	219	1	1	1
KPE 352	220	220	220	219	219	219	1	1	1
MBR 37	220	220	220	219	219	219	1	1	1
KPE 166	220	220	220	219	219	219	1	1	1
MBR 324	220	220	220	219	219	219	1	1	1
MBR 72	220	220	220	219	219	219	1	1	1

MBR 133	220	220	220	219	219	219	1	1	1
MBR 112	220	220	220	219	219	219	1	1	1
KRN 267	220	220	220	219	219	219	1	1	1
MBR 423	220	220	220	219	219	219	1	1	1
MBR 229	220	220	220	219	219	219	1	1	1
MBR 314	220	220	220	219	219	219	1	1	1
KRN 78	220	220	220	219	219	219	1	1	1
KRN 130	220	220	220	219	219	219	1	1	1
KRN 150	220	220	220	219	219	219	1	1	1
KRN 387	220	220	220	219	219	219	1	1	1
KRN 209	220	220	220	219	219	219	1	1	1
TJP 129	220	220	220	219	219	219	1	1	1
TJP 361	220	220	220	219	219	219	1	1	1
TJP 126	220	220	220	219	219	219	1	1	1
33TJP 167	220	220	220	219	219	219	1	1	1

3. Regulation Voltage Calculation

Calculation of voltage regulation based on equation (2). Where the data used to analyze voltage regulation is the result of the voltage drop in Table 6 below.

Table 6. Regulation voltage calculation

Substations	Sending voltage			Receice voltage			Regulation voltage		
	R	S	T	R	S	T	R	S	T
KPE 155	220	220	220	219	219	219	0,004566	0,004566	0,004566
KPE 92	220	220	220	219	219	219	0,004566	0,004566	0,004566
KPE 42	220	220	220	219	219	219	0,004566	0,004566	0,004566
KPE 62	220	220	220	219	219	219	0,004566	0,004566	0,004566
KPE 228	220	220	220	219	219	219	0,004566	0,004566	0,004566
KPE 399	220	220	220	219	219	219	0,004566	0,004566	0,004566
KPE 36	220	220	220	219	219	219	0,004566	0,004566	0,004566
KPE 52	220	220	220	219	219	219	0,004566	0,004566	0,004566
KPE 388	220	220	220	219	219	219	0,004566	0,004566	0,004566
KPE 165	220	220	220	219	219	219	0,004566	0,004566	0,004566
KPE 53	220	220	220	219	219	219	0,004566	0,004566	0,004566
KPE 352	220	220	220	219	219	219	0,004566	0,004566	0,004566
MBR 37	220	220	220	219	219	219	0,004566	0,004566	0,004566
KPE 166	220	220	220	219	219	219	0,004566	0,004566	0,004566
MBR 324	220	220	220	219	219	219	0,004566	0,004566	0,004566
MBR 72	220	220	220	219	219	219	0,004566	0,004566	0,004566
MBR 133	220	220	220	219	219	219	0,004566	0,004566	0,004566
MBR 112	220	220	220	219	219	219	0,004566	0,004566	0,004566
KRN 267	220	220	220	219	219	219	0,004566	0,004566	0,004566
MBR 423	220	220	220	219	219	219	0,004566	0,004566	0,004566
MBR 229	220	220	220	219	219	219	0,004566	0,004566	0,004566

MBR 314	220	220	220	219	219	219	0,004566	0,004566	0,004566
KRN 78	220	220	220	219	219	219	0,004566	0,004566	0,004566
KRN 130	220	220	220	219	219	219	0,004566	0,004566	0,004566
KRN 150	220	220	220	219	219	219	0,004566	0,004566	0,004566
KRN 387	220	220	220	219	219	219	0,004566	0,004566	0,004566
KRN 209	220	220	220	219	219	219	0,004566	0,004566	0,004566
TJP 129	220	220	220	219	219	219	0,004566	0,004566	0,004566
TJP 361	220	220	220	219	219	219	0,004566	0,004566	0,004566
TJP 126	220	220	220	219	219	219	0,004566	0,004566	0,004566
TJP 167	220	220	220	219	219	219	0,004566	0,004566	0,004566

4. Calculation of 1 Phase Load Voltage Drop

The calculation of the voltage drop on a 1-phase load based on equation (3) is shown in Table 7. This equation is used to test the voltage drop that occurs on low-voltage lines using current, resistance, reactance, and cable length data.

Table 7. Calculation of 1 phase load voltage drop

Substations	Current			Cos	Sin	Resistance			Reactance			Length	Length cable SR			Drop voltage		
	R	S	T	φ	φ	R	S	T	R	S	T	Cable JTR	R	S	T	R	S	T
KPE 155	3,3	3,3	3,3	0,85	0,526	0,311	0,302	0,300	0,075	0,074	0,074	500	20	13	12	1,003	0,974	0,970
KPE 92	3,3	3,3	3,3	0,85	0,526	0,247	0,247	0,246	0,060	0,060	0,060	400	15	15	14	0,798	0,798	0,794
KPE 42	3,3	3,3	3,3	0,85	0,526	0,304	0,300	0,302	0,074	0,074	0,074	500	15	12	13	0,982	0,970	0,974
KPE 62	3,3	3,3	3,3	0,85	0,526	0,364	0,358	0,361	0,089	0,088	0,088	600	17	13	15	1,175	1,158	1,166
KPE 228	3,3	3,3	3,3	0,85	0,526	0,387	0,385	0,385	0,095	0,095	0,095	650	13	12	12	1,250	1,246	1,246
KPE 399	3,3	3,3	3,3	0,85	0,526	0,323	0,326	0,324	0,079	0,080	0,079	540	12	14	13	1,043	1,052	1,048
KPE 36	3,3	3,3	3,3	0,85	0,526	0,302	0,302	0,304	0,074	0,074	0,074	500	13	13	15	0,974	0,974	0,982
KPE 52	3,3	3,3	3,3	0,85	0,526	0,331	0,333	0,331	0,081	0,081	0,081	550	14	15	14	1,070	1,074	1,070
KPE 388	3,3	3,3	3,3	0,85	0,526	0,300	0,300	0,302	0,074	0,074	0,074	500	12	12	13	0,970	0,970	0,974
KPE 165	3,3	3,3	3,3	0,85	0,526	0,338	0,336	0,337	0,083	0,082	0,083	560	15	13	14	1,093	1,084	1,089
KPE 53	3,3	3,3	3,3	0,85	0,526	0,327	0,324	0,323	0,080	0,079	0,079	540	15	13	12	1,056	1,048	1,043
KPE 352	3,3	3,3	3,3	0,85	0,526	0,317	0,321	0,320	0,078	0,078	0,078	530	12	15	14	1,025	1,038	1,033
MBR 37	3,3	3,3	3,3	0,85	0,526	0,414	0,418	0,414	0,102	0,103	0,102	700	12	15	12	1,338	1,350	1,338
KPE 166	3,3	3,3	3,3	0,85	0,526	0,347	0,349	0,345	0,085	0,085	0,085	576	15	16	13	1,122	1,126	1,114
MBR 324	3,3	3,3	3,3	0,85	0,526	0,324	0,321	0,324	0,079	0,079	0,079	534	15	13	15	1,045	1,037	1,045
MBR 72	3,3	3,3	3,3	0,85	0,526	0,314	0,312	0,312	0,077	0,076	0,076	520	14	12	12	1,015	1,007	1,007
MBR 133	3,3	3,3	3,3	0,85	0,526	0,303	0,310	0,307	0,074	0,075	0,075	505	12	17	15	0,979	1,000	0,992
MBR 112	3,3	3,3	3,3	0,85	0,526	0,335	0,340	0,339	0,082	0,083	0,083	556	14	18	17	1,081	1,098	1,094
KRN 267	3,3	3,3	3,3	0,85	0,526	0,347	0,351	0,351	0,085	0,086	0,086	583	12	15	15	1,123	1,135	1,135
MBR 423	3,3	3,3	3,3	0,85	0,526	0,365	0,367	0,360	0,089	0,090	0,089	606	15	17	12	1,177	1,186	1,165
MBR 229	3,3	3,3	3,3	0,85	0,526	0,305	0,309	0,307	0,074	0,075	0,075	503	14	17	16	0,984	0,996	0,992
MBR 314	3,3	3,3	3,3	0,85	0,526	0,377	0,379	0,383	0,093	0,093	0,094	636	12	13	16	1,220	1,224	1,237
KRN 78	3,3	3,3	3,3	0,85	0,526	0,350	0,346	0,346	0,086	0,085	0,085	578	16	13	13	1,130	1,118	1,118
KRN 130	3,3	3,3	3,3	0,85	0,526	0,403	0,403	0,402	0,099	0,099	0,099	679	13	13	12	1,303	1,303	1,299

KRN 150	3,3	3,3	3,3	0,85	0,526	0,348	0,346	0,350	0,085	0,085	0,086	580	14	12	15	1,125	1,117	1,130
KRN 387	3,3	3,3	3,3	0,85	0,526	0,392	0,392	0,393	0,096	0,096	0,096	654	15	15	16	1,266	1,266	1,270
KRN 209	3,3	3,3	3,3	0,85	0,526	0,351	0,353	0,353	0,086	0,087	0,087	590	12	13	13	1,135	1,140	1,140
TJP 129	3,3	3,3	3,3	0,85	0,526	0,311	0,313	0,309	0,076	0,076	0,076	515	14	15	12	1,006	1,010	0,997
TJP 361	3,3	3,3	3,3	0,85	0,526	0,307	0,312	0,308	0,075	0,076	0,075	512	12	16	13	0,992	1,009	0,996
TJP 126	3,3	3,3	3,3	0,85	0,526	0,453	0,455	0,454	0,112	0,112	0,112	766	13	15	14	1,463	1,472	1,468
TJP 167	3,3	3,3	3,3	0,85	0,526	0,335	0,332	0,336	0,082	0,082	0,082	556	14	12	15	1,081	1,073	1,085

From the table above the load values for 1 phase are the same but because of the values of cos φ, sin φ, resistance, reactance, the length of the low voltage network cable along with the size and type of resistance, the voltage drop value for each house is different but almost close.

C. Voltage Drop Tolerance allowed by PLN

According to SPLN Number 72 of 1987, the allowable voltage drop for each type of connection is as follows:

1. The voltage drop on the intermediate voltage network is allowed [10]:
   - 2% of the working voltage as specified in paragraph 22 for systems that do not utilize STB (i.e. Spindle and Cluster systems).
   - 5% of the working stress for systems that utilize STB, namely radial systems on the ground and node systems.
2. The voltage drop on the distribution transformer is allowed 3% of the working voltage.
3. The voltage drop at low voltage connections is allowed up to 4% of the working voltage depending on the load density.
4. The voltage drop at the house connection is allowed 1% of the nominal voltage.

Based on field measurements and simulations, one of the case studies was on the KPE 155 transformer located in Village 6. The calculations below are intended to control the voltage drop tolerance allowed by SPLN.

1. Measurement Voltage Drop Data

   The data used to test the tolerance limit for the voltage drop allowed by the SPLN is the measurement data in Table 1 above.

Table 8. Calculation of Voltage Drop Tolerance

Substation	Sending voltage (V_r)			Drop voltage (ΔV)			Tolerance limit		
	R	S	T	R	S	T	R	S	T
KPE 155	220	222	219	2	1	2	0,91	0,45	0,91
KPE 92	222	220	223	1	2	1	0,45	0,91	0,45
KPE 42	213	214	212	2	2	2	0,94	0,93	0,94
KPE 62	209	208	208	2	2	2	0,96	0,96	0,96
KPE 228	222	221	223	2	2	2	0,90	0,90	0,90
KPE 399	220	224	222	2	2	2	0,91	0,89	0,90
KPE 36	219	219	221	2	2	2	0,91	0,91	0,90
KPE 52	221	221	220	2	2	2	0,90	0,90	0,91
KPE 388	225	224	223	2	2	3	0,89	0,89	1,35
KPE 165	221	223	222	2	2	2	0,90	0,90	0,90
KPE 53	220	221	221	2	2	2	0,91	0,90	0,90
KPE 352	221	223	222	2	2	2	0,90	0,90	0,90
MBR 37	220	221	219	2	2	2	0,91	0,90	0,91
KPE 166	221	222	220	8	2	3	3,62	0,90	1,36

MBR 324	222	223	224	2	2	2	0,90	0,90	0,89
MBR 72	217	217	219	2	2	1	0,92	0,92	0,46
MBR 133	221	219	219	1	1	2	0,45	0,46	0,91
MBR 112	222	220	221	1	3	3	0,45	1,36	1,36
KRN 267	221	224	223	3	2	2	1,36	0,89	0,90
MBR 423	224	223	224	2	2	2	0,89	0,90	0,89
MBR 229	219	222	220	1	1	1	0,46	0,45	0,45
MBR 314	220	221	221	3	1	2	1,36	0,45	0,90
KRN 78	220	221	220	2	2	3	0,91	0,90	1,36
KRN 130	220	221	220	3	3	3	1,36	1,36	1,36
KRN 150	219	220	219	1	2	1	0,46	0,91	0,46
KRN 387	221	222	221	2	2	3	0,90	0,90	1,36
KRN 209	221	220	221	2	1	2	0,90	0,45	0,90
TJP 129	223	221	222	2	3	1	0,90	1,36	0,45
TJP 361	219	220	220	1	1	1	0,46	0,45	0,45
TJP 126	219	220	219	3	2	3	1,37	0,91	1,37
TJP 167	220	221	220	3	3	2	1,36	1,36	0,91

Based on Table 8 above, it can be seen the calculation results of each transformer in each phase shows the tolerance limit for the voltage drop allowed by the SPLN. The highest value of the tolerance limit is found in the KPE 166 transformer in phase R at 3.62%, while the lowest value of the tolerance limit is 0.45%. The tolerance limit allowed by SPLN is 5%, so the voltage drop that occurs in Feeder 5 outgoing Villages 4 and 6 is still within the tolerance limit allowed by SPLN.

2. Voltage Drop Data Based on Simulation Results

The data used to test the allowable voltage drop tolerance limit by SPLN is the simulation data in Table 5. After the 3-phase voltage is converted to 1-phase voltage, it will then be analyzed and produce a voltage drop from the simulation data. Simulation data of the voltage drop tolerance limit can be seen in Table 9 below.

Table 9. Calculation of Simulation Voltage Drop Tolerance

Nama Gardu	Tegangan Terima			Jatuh Tegangan			Batas Toleransi		
	R	S	T	R	S	T	R	S	T
KPE 155	219	219	219	1	1	1	0,46	0,46	0,46
KPE 92	219	219	219	1	1	1	0,46	0,46	0,46
KPE 42	219	219	219	1	1	1	0,46	0,46	0,46
KPE 62	219	219	219	1	1	1	0,46	0,46	0,46
KPE 228	219	219	219	1	1	1	0,46	0,46	0,46
KPE 399	219	219	219	1	1	1	0,46	0,46	0,46
KPE 36	219	219	219	1	1	1	0,46	0,46	0,46
KPE 52	219	219	219	1	1	1	0,46	0,46	0,46
KPE 388	219	219	219	1	1	1	0,46	0,46	0,46
KPE 165	219	219	219	1	1	1	0,46	0,46	0,46
KPE 53	219	219	219	1	1	1	0,46	0,46	0,46
KPE 352	219	219	219	1	1	1	0,46	0,46	0,46

MBR 37	219	219	219	1	1	1	0,46	0,46	0,46
KPE 166	219	219	219	1	1	1	0,46	0,46	0,46
MBR 324	219	219	219	1	1	1	0,46	0,46	0,46
MBR 72	219	219	219	1	1	1	0,46	0,46	0,46
MBR 133	219	219	219	1	1	1	0,46	0,46	0,46
MBR 112	219	219	219	1	1	1	0,46	0,46	0,46
KRN 267	219	219	219	1	1	1	0,46	0,46	0,46
MBR 423	219	219	219	1	1	1	0,46	0,46	0,46
MBR 229	219	219	219	1	1	1	0,46	0,46	0,46
MBR 314	219	219	219	1	1	1	0,46	0,46	0,46
KRN 78	219	219	219	1	1	1	0,46	0,46	0,46
KRN 130	219	219	219	1	1	1	0,46	0,46	0,46
KRN 150	219	219	219	1	1	1	0,46	0,46	0,46
KRN 387	219	219	219	1	1	1	0,46	0,46	0,46
KRN 209	219	219	219	1	1	1	0,46	0,46	0,46
TJP 129	219	219	219	1	1	1	0,46	0,46	0,46
TJP 361	219	219	219	1	1	1	0,46	0,46	0,46
TJP 126	219	219	219	1	1	1	0,46	0,46	0,46
TJP 167	219	219	219	1	1	1	0,46	0,46	0,46

Based on Table 9, it can be seen that the results of the simulation data calculations show that the voltage drop is still within the tolerance limit allowed by the SPLN, which is 5%.

5. Conclusion

Based on the results of the analysis of calculations between measurement data and simulation data carried out on feeder 5 outgoing villages 4 and 6 it can be concluded, as follows:

A. For data from measurements and simulations, there is a voltage drop. For measurements, the largest voltage drop is found in the KPE 166 transformer at phase R of 8 Volts, phase S of 2 Volts, and phase T of 3 Volts, but it is still within the SPLN tolerance limit. Then for the KPE 62 transformer, there was a voltage drop of 2 Volts for phases R, S, and T but it had exceeded the SPLN tolerance limit of 5%. As for the simulation, the KPE 166 transformer only has a voltage drop of 1 volt for phases R, S, and T.
B. In the calculation of the voltage drop on a 1-phase load, there is a voltage drop. For measurement data, the largest voltage drop occurred in the KPE 62 transformer in the R phase at 2.150 Volts, in the TJP 126 transformer in the S phase at 2.065 Volts, and in the KPE 165 transformer in the R phase at 2.010 Volts. Whereas for the simulation data, the largest voltage drop occurs in the TJP 126 transformer at phase S of 1.472 Volts, phase T of 1.468 Volts, and phase R of 1.463 Volts.
C. In this research to compare the voltage drop that occurs in analytical calculations and simulation results is to use the MAPE equation. Based on the MAPE calculation results, namely: MAPE phase R of 44.22043 percent, MAPE phase S of 42.47312 percent and MAPE phase T of 44.08602 percent. However, overall the results of the MAPE calculations are respectable.

References

[1] H. L. Latupeirissa, H. Muskita, and C. Leihitu, "Analisis Kerugian Tegangan Pada Jaringan Tegangan Rendah (Jtr) 380/220 Volt Gardu Distribusi Politeknik Negeri Ambon," *J. Simetrik*, vol. 8, no. 1, pp. 46–51, 2018, doi: 10.31959/js.v8i1.79.

[2] A. Kurniawan, "Analisa Jatuh Tegangan dan Penanganan Pada Jaringan Distribusi 20 kV Rayon Palur PT. PLN (Persero) menggunakan etap 12.6 publikasi ilmiah," p. 15, 2016, [Online]. Available: http://eprints.ums.ac.id/50011/

[3] K. Naim, N. Muhtar, N. Nurismawati, and I. Setiawan, "Rekonfigurasi JTR Akibat Tingginya Rugi Daya dan Jatuh Tegangan Pada Area BTN Hamzy dan BTN Antara," *J. Teknol. Elekterika*, vol. 14, no. 2, p. 105, 2017, doi: 10.31963/elekterika.v14i2.1218.

[4] N. J. Hontong, M. T. ST. MT., and L. S. P. ST. MT., "Analisa Rugi – Rugi Daya Pada Jaringan," *E-jurnal Tek. elektro*, pp. 64–71, 2015.

[5] Achmad Deni Mulyadi, "Pengaruh Ketidakseimbangan Beban Pada Rugi Daya Saluran Netral Jaringan Distribusi Tegangan Rendah," *J. Tek. Energi*, vol. 1, no. 1, pp. 11–15, 2020, doi: 10.35313/energi.v1i1.1801.

[6] S. Baqaruzi and A. Muhtar, "Analisis Jatuh Tegangan dan Rugi-rugi Akibat Pengaruh Penggunaan Distributed Generation Pada Sistem Distribusi Primer 20 KV," *E-JOINT (Electronica Electr. J. Innov. Technol.*, vol. 1, no. 1, pp. 20–26, 2020, doi: 10.35970/e-joint.v1i1.216.

[7] I. W. S. Nindiyubudoyo, "Proteksi Sistem Distribusi Tenaga Listrik," *Garamound*, vol. 2, p. 375, 2012.

[8] N. Septiani, S. Thaha, and N. Muchtar, "Analisis Drop Tegangan Pada Jaringan Tegangan Rendah PT . PLN (Persero) Unit Layanan Pelanggan (ULP) Panakkukang," in *Seminar Nasional Teknik Elektro dan Informatika (SNTEI)*, 2021, vol. 3, no. September, pp. 129–135.

[9] I. Mado, A. Soeprijanto, and Suhartono, "Applying of Double Seasonal Arima Model For Electrical Power Demand Forecasting at PT. PLN Gresik Indonesia," *Int. J. Electr. Comput. Eng.*, vol. 8, no. 6, pp. 4892–4901, 2018, doi: 10.11591/ijece.v8i6.pp.4892-4901.

[10] F. D. Safitri, "Simulasi Penempatan Transformator Pada Jaringan Distribusi Berdasarkan Jatuh Tegangan Menggunakan ETAP Power Station 12.6.0," *J. Edukasi Elektro*, vol. 4, no. 1, 2020, doi: 10.21831/jee.v4i1.29315.

Biographies of Authors

Marthen Arifin is an Electrical Engineering Student at Universitas Borneo Tarakan in 2018. The author was born in Sengayan on March 21st, 2001. Before becoming a student, the author had completed his education at SMA Negeri 5 Malinau.

Ismit Mado graduated from the Doctoral Program at ITS Surabaya in 2019. Currently, He is the Head of Power System Stability Laboratory at the Department of Electrical Engineering, Universitas Borneo Tarakan. He is interested in stability and control studies of power generation systems, forecasting studies based on time series models, and fuzzy modeling.

Achmad Budiman is a Lecturer in Electrical Engineering since 2002. He obtained a Bachelor's degree in electrical engineering from Universitas Gadjah Mada, Yogyakarta. He graduated with a Master's degree in electrical engineering from ITS Surabaya. Currently, He is the Head of the Electrical Engineering Department, at Universitas Borneo Tarakan. He is interested in the field of stability in the power distribution and transmission system.

Choirul Anwar graduated with a Diploma degree in Mechanical Engineering from the Institut Teknologi Nasional, Malang in 2005. Since 2006 he has been accepted as an employee of PT. PLN (Persero) and is currently a Manager of the customer service unit of PT. PLN (Persero) Tarakan City.

Samuel Nathanael graduated with a vocational program diploma from the University of North Sumatra in 2019. He has worked since 2020 at PT PLN (Persero) Tarakan City in the Distribution Section.